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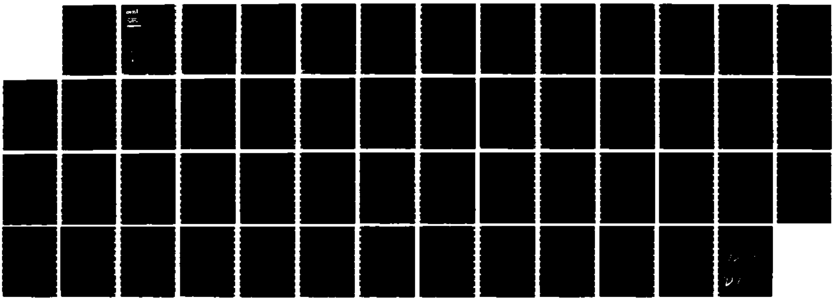

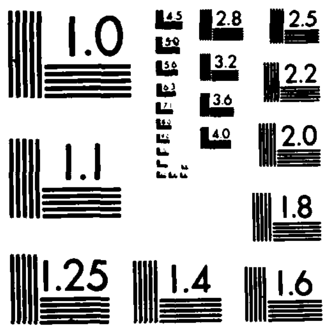

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The Provisioning of Water in Emergencies: A Research Assessment

A. H. Voelker

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THE PROVISIONING OF WATER IN EMERGENCIES: A RESEARCH ASSESSMENT

A. H. Voelker

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EXECUTIVE SUMMARY

This document is one of a series being prepared for the Federal Emergency Management Agency (FEMA) by the Oak Ridge National Laboratory (ORNL) to assess (1) the adequacy of the research base underlying FEMA programs, (2) the adequacy with which the research base is being applied to the programs, and (3) the need for additional research. This assessment covers the provisioning of water during a full range of emergencies. Information for the assessment was obtained from the disaster literature; Federal, State, and local emergency plans; and discussions with individuals working in emergency planning.

The review of available sources demonstrated just how little attention water provisioning has received in the disaster literature. If treated at all, water systems have been combined with other "public works" and given scant attention. Difficulties in the provisioning of water have generally been overlooked, and it is often assumed that water systems can respond effectively to any level of emergency and manage their own rehabilitation. Postdisaster experience described in the assessment shows that these assumptions are not necessarily valid.

The assessment begins by demonstrating the importance of water to the functioning of our technological society. The dependence of industry, agriculture, and domestic systems on large reliable supplies of clean water is described. In particular, the impacts of decreased flow on urban areas are noted. Flow reductions that cause a shortage of process water can expose a city to risks of uncontrolled fires, health threats from sewage that cannot be transported to treatment facilities, temporary loss of income, and disruption of business.

To demonstrate the impacts of water system failure upon communities, two modern examples of such failures (Trenton, N.J. and San Fernando, Calif.) are described. In 1975, a relatively minor component failure in the water system of Trenton, N.J., initiated a train of events that led to a major water emergency lasting one week. At the peak of the emergency, parts of the city had to be supplied by tank truck. An abnormally low flow was maintained in the remainder of Trenton by having 90 fire trucks pump water from neighboring communities into fire hydrants at the extremities of the city. In addition to stress and ill will, another major impact was economic -- magnified by the forced lay-off of almost 40,000 workers.

The city of San Fernando was hit by a moderate earthquake in February of 1971. Extensive damage was experienced by the city: 363 breaks in water and sewage mains, altogether about 1500 leaks, and damage to 25 facilities including treatment, pressure control, and pumping plants. The nearby Van Norman Dam complex was severely shaken, causing the evacuation of 80,000 people from the potential inundation area and requiring the lowering of its

reservoir. Total earthquake damage was estimated at $500 million, and more than 60 lives were lost.

The examples described above represent extreme situations; few of the thousands of outages that occur each year become major emergencies. However, the impacts experienced by Trenton and San Fernando show clearly the potential disruption that can follow system failures. This potential justifies emergency preparedness adjustments on the part of water utilities. Such emergency prepreparedness adjustments can help to decrease the vulnerability of water systems to emergencies.

At the same time, there are a number of factors constantly at work to <u>increase</u> the vulnerability of water systems, thereby decreasing the system's ability to maintain minimum flow during supply disruptions. These include (1) a continuing growth in demand, producing increased dependency of urban populations on reliable water supplies, particularly in periods of low flow or in the event of equipment failure; (2) increased difficulties in securing additional sources, including sites for well fields and reservoirs; (3) inappropriate revenue structures that inhibit maintenance, renovation, and emergency preparedness; and (4) increased sophistication in water system technology that requires highly trained staff and management dedication to modern operating principles, including emergency preparedness. The literature shows that there has been very little research to determine the actual and evolving vulnerability of water systems or the emergency preparedness and response capabilities of water systems. Research in these areas should be given priority by the preparedness community.

The most serious impacts to water systems are probably those that would result from a nuclear attack. Since national emergencies are of particular interest to FEMA, a special effort was made to review civil defense literature concerning the provisioning of water. Past assessments have concluded that water utilities will be on-line before shelter stores of water are consumed and that flows during the recovery period, while reduced, will be sufficient to support recovery operations. However, the assumptions and methodologies underlying these conclusions are questionable and are challenged in this assessment. The following difficulties are pointed out.

1. Single-weapon, single-city assessments do not identify the cumulative impacts that would occur in a more realistic attack scenario that would decrease the possibility of regional assistance, particularly in power and water, and that would result in severe shortages of spare parts and skilled personnel.

2. Damage estimates for a given city are likely to be higher than those used. A multiple-weapon pattern may be more likely, given the proliferation of Soviet warheads, and would be more damaging.

3. Potential impacts from electromagnetic pulse (EMP) are either ignored or assumed to be negligible. Recent research on this phenomenon coupled with utilities' increased reliance on electronic control suggests that assumptions about the effects of EMP should be reexamined.

4. Social science research suggests that for a number of psychological reasons, waterworks employees will not be as dedicated or productive as assumed in past assessments. This would impede system restoration.

5. None of the major assessments of the impacts of nuclear attack consider the recently hypothesized phenomenon of Nuclear Winter. Consensus on the validity of this hypothesis and the magnitude of possible impacts to continental climates is yet to be achieved, scenarios proposed to date would severly impact water distribution systems, particularly in the South, through freezing temperatures. As a consensus on temperature modification develops, the impacts on water systems should be examined.

6. The small inventories of treatment chemicals maintained by water treatment facilities will most certainly lead to shortages of these chemicals in host areas. Reduced water treatment will create threats of disease, especially for a population crowded into host areas.

Assessments incorporating the above considerations are likely to show that water systems are much more vulnerable to nuclear attack than previously assumed and that effects would be more prolonged.

The literature reviewed has left more questions unanswered than answered. It shows that emergency managers have tended to ignore the impact of emergencies on water systems, perhaps because water supply has been a serious problem in only a handful of past emergencies. Support of the following program improvements and research topics would help to promote the consideration of water provisioning in emergency management.

The following improvements in emergency management planning are needed.

1. Supplemental Guidelines for Preparing Integrated Emergency Management Plans. Guidelines are needed for performing the analysis to generate data for FEMA's integrated emergency management forms. Guidance on estimating preparedness resources and creating a realistic development plan would be helpful. (FEMA, 1985b) Suggestions for determining the effectiveness of various adjustments dealing with emergency water and for choosing among adjustments should be prepared to supplement the present guidelines. Suggestions for overcoming institutional barriers and "marketing" adjustments would be helpful.

2. Background on Water Systems for the Local Emergency Planner. To broaden local emergency planners' understanding of the importance of water systems and of appropriate preparedness adjustments for water systems, a background guideline in the integrated Emergency Management series should be prepared for use in interacting with utilities and in integrating the emergency water plan into the greater community plan.

The following are research needs consistent with FEMA's interests in the overall state of the nation's preparedness and with its interest in promoting effective emergency planning.

1. Vulnerability of Water Systems. A study is needed to determine the level of vulnerablity of water systems to a range of emergencies. This would require a determination of the state of emergency preparedness and response capability through interviews with operating personnel and surveys of operating systems.

2. Improvements in the Design and Acceptance of Preparedness Adjustments. Studies are needed to determine institutional barriers to the adoption of such adjustments as emergency planning, regional agreements for emergency support and cooperation, and ways to improve communications among waterworks staff, city and state officials, and the press during an emergency.

3. The Impact of Nuclear Attack on Water Systems. Many unanswered questions remain concerning the impact of nuclear attack on water systems. Useful research can be done on any of the following:

   a. The effect of EMP on utilities.

   b. The effect of temperature change and possible drought on utilities in the event of a Nuclear Winter.

   c. The significance of the almost total dependence of water systems on electrical utilities - a national assessment.

   d. The feasibility of stockpiling potable water and waste water treatment chemicals.

   e. The difficulty of cleaning water supplies after nuclear attack and a plan for accomplishing the cleanup.

   f. The effect on water supplies by spills of toxic substances.

Since assuming lead agency responsibility related to water preparedness in 1983, the U.S. Army Corps of Engineers (USACE) has developed an ambitious Emergency Water Planning Program to address a full spectrum of disasters. The program plan calls for

a mix of research and operational capability development including two prototype studies to develop emergency water plans for two cities. This activity is of special interest to FEMA since such plans should be coordinated and consistent with the integrated emergency management plans for the areas sponsoring the prototypes to avoid duplication and perhaps conflicting inputs to local planners. We recommend that any research undertaken by FEMA in the area of water provisioning be compatible with and supportive of the USACE Emergency Water Planning Program. Ideally, joint efforts should be promoted through interagency agreements using needs identified in this assessment as a basis for preliminary discussions. This would allow FEMA to contribute to emergency water research in a meaningful way with a minimum investment.

THE PROVISIONING OF WATER IN EMERGENCIES: A RESEARCH ASSESSMENT

A. H. Voelker

This assessment of the

ABSTRACT

The provisioning of water during and after national or civil emergencies has been given scant attention by emergency planners. This assessment of the limited literature base has four goals: (1) to determine if emergencies can result in water shortages, (2) to determine if the unavailability of water can seriously impact communities, (3) to determine if the understanding of water shortage impacts has been incorporated into the programs of the Federal Emergency Management Agency (FEMA), and (4) to suggest research needs regarding emergency water preparedness, consistent with the interests of FEMA.

Case histories and the discussions of emergency preparedness needs of utilities contained in the literature suggest that ~~a number of~~ several factors are at work to increase the vulnerability of modern water systems. Major emergencies can cause flow reductions resulting in severe impacts to communities including the inability to effectively control the spread of fire, health threats from sewage not transported to treatment facilities, loss of income, business disruption, increased water system repair and administration costs, loss of water revenues, and possible relocation of the affected population.

Recommended improvements to FEMA programs that influence the preparedness and response of water systems include (1) the expansion of the integrated Emergency Management guidelines and workbooks to focus more attention on utilities including water systems and (2) the development of background materials to help emergency planners understand the nature of water systems, impacts resulting from their disruption, and practical emergency adjustments for water systems. are provided

Recommended research that is consistent with FEMA's overall responsibilites includes: (1) studies to determine the current and future level of vulnerability of water systems to a range of emergencies, (2) studies to improve the design and acceptance of preparedness adjustments, and (3) studies to assess the impacts of nuclear attack on water systems.

1. THE IMPORTANCE OF WATER

1.1 WATER USE

The average American has come to expect unlimited supplies of low-cost, high-quality water on demand. Water supply is regarded as a service by the general public, and statistics reveal a steady increase in per capita water consumption in recent times despite the fact that water purveyors are finding it increasingly more difficult to locate and develop new sources. The trend of increased consumption, while slowing somewhat, is projected to continue. Overman (1969) lists the increase in the per capita consumption of water as approximately one percent per year.

In reality, it is poor public policy to treat water as an inexhaustible resource. Water is as important to our intensely urbanized society as petroleum and electricity. While the price of petroleum and electricity normally reflects development, production, and maintenance costs, subsidies and political control of rate structures by locally controlled and financed water utilities maintain artifically low water prices, below levels needed to support adequate maintenance, renovation, and expansion. Many experts feel it is time to price water as a commodity rather than a service, thereby ensuring the development of future supplies in a timely manner and reducing wastage (Overman, 1969).

Water is important for industry, agriculture, and domestic use. Of the total water withdrawn from surface and groundwater sources in 1975 (Water Resources Council, 1978), 37 percent went to support manufacturing and energy production, 52 percent was used by agriculture, and only 11 percent was taken by public supply systems for domestic use. The large amount of water required by various manufacturing processes is generally unappreciated. For every kilogram of steel produced, nearly 300 kg of water are consumed by the process, for every kilogram of paper, 250 kg of water are consumed, and for every kilogram of nitrate fertilizer, 600 kg of water are consumed. Furthermore, water is needed by industry for the transfer of heat; in heat exchangers, for the conversion of heat into mechanical energy, and as a general coolant. The withdrawal of water for cooling thermal electric plants is the largest single water use in the United States.

Without irrigation, agricultural output would be greatly reduced. Ten percent of the nation's farms practice irrigation (42 million acres of the 460 million acres of developed cropland), and irrigated lands produce 20 percent of the value of all farm corps (Warrick, 1975). In recent times, irrigation practices have even been introduced in the humid East.

The total water withdrawals associated with each of the three use categories above are huge and commonly expressed in billions of gallons per day. Withdrawals for industry, agricul-

ture and public and rural systems were 148 billion gal./d, 159 billion gal./d, and 28.8 billion gal./d respectively in 1975 (WRC, 1975). Actual water consumption (difference between withdrawals and wastewater outflow) was considerably less, totaling 8.7 billion gal./d by industry, 86.4 billion gal./d by agriculture, and 7.4 billion gal./d by public and rural systems. Water use by the manufacturing industry is a good example of why consumption is so much less than withdrawal. Water is recycled twice on the average by the typical manufacturing plant before being returned to the source. Then only ten percent of this water is consumed by evaporation or incorporation into products.

Great variability in local consumption caused by specialized uses, such as local industry and lawn watering make a single national estimate of per capita domestic consumption meaningless for any given location, but a commonly accepted average is 100 gal./d. The heavy use of domestic water for gardening and lawn use in the west can easily increase the local per capita consumption to more than 400 gal./d.

The discussion above demonstrates our dependence on huge quantities of useable water on demand. However, low cost and a general abundance of water have fostered the habit of waste. Voluntary reductions during periods of water shortage have shown that use can be reduced by 40 percent with minimal inconvenience. Even this level is far more than the survival level of 4 liters of water per day for a faimly of four. In light of the gap between normal use and the amount of water needed for postdisaster survival, is the provisioning of water during emergencies an issue for emergency planners? The remainder of this assessment looks to the existing literature for an answer to this question.

1.2 THE SIGNIFICANCE OF REDUCED SUPPLY

The contrast between levels of water needed for human survival and the much larger capacity of public and private water systems helps explain why disaster victims do not die from lack of water, particularly since it is usually possible to truck or pump emergency water from neighboring areas. However, in a major disaster such as an earthquake where the distribution system is disrupted, importing water in the huge quantities needed by a large metropolitian area may not be feasible. Also, if nearby sources of trucked or piped water of sufficient size are not available as was the case in the 1972 earthquake in Managua, Nicaragua, the population must be evacuated to areas that have operative water systems and safe drinking water supplies, once the water stored in the distribution system is depleted.

For most water emergencies short of a serious earthquake or nuclear attack, water supply is more likely to be reduced than eliminated. Even if the reduced supply is adequate to satisfy drinking water needs, however, this does not mean that providing water is not a problem. The pressure and volume of most metropolitan systems are set by the maximum expected fire threat, and

the loss of required fire flow puts a community at serious risk from fire. Neighboring communities who furnish emergency water also increase their fire risk through loss of reserve capacity and reduced pressure.

There is yet another threat from reduced flow levels in systems serving large concentrations of people. Modern cities are totally dependent on large quantities of water to operate wastewater disposal facilities that remove and process waste. While drinking water may be trucked in to disaster victims, it is impractical to truck out sewage. For existing waste treatment systems to function properly, sufficient water must flow through gravity-flow sewers to ensure cleansing action -- otherwise septic conditions will develop and serious health problems can arise. It is also possible for waste treatment plants to suffer process failures if input flows fall below design limits. Although generally not appreciated as a serious implication of reduced or missing water supplies, waste disposal may constitute a more serious problem than provisioning drinking water in major emergencies.

Significant secondary impacts are also likely to result from reduced water supply. For instance, recovery activities such as the decontamination of buildings and equipment in the event of nuclear attack would be extremely difficult. Serious economic loss can be experienced through reduced employment, as business and industry are forced to curtail activities because of water shortages. Even the water system suffers economic loss above the cost of repair since its revenues are reduced until full service is finally restored. It is ironic that revenues are reduced just when the water system needs additional funds to cover restoration costs. Typically water rates must be increased after significant reductions in output. Customers have difficulty accepting such increases, particularly after a drought when they may have made voluntary reductions only to be rewarded with rate increases.

Because of the vital importance of maintaining sufficient flow and pressure in community water systems after a disaster, the topic of provisioning water must be extended beyond basic human survival to include the problem of providing adequate water for fire protection, maintaining sanitary conditions for the population, and keeping people employed. This requires an operative water system after the disaster, with capacity close to preemergency levels. For this reason, the charge of this assessment, to review the research base of emergency water provisioning, must consider the ability of the 60,000 water systems in this country to deliver the minimum level of water required to protect the health and safety of the population and the viability of the local economy in the event of an emergency.

1.3 WATER SYSTEMS - A PRIMARY FOCUS

The purpose of a municipal water-supply system is to provide potable water that is chemically and bacteriologically safe for human consumption and that is of adequate quality for industrial users. The system may be viewed as made up of (1) a water source, usually a combination of groundwater aquifers, rivers, lakes, reservoirs, and rarely the ocean; (2) a collection system transporting water from the source; (3) a treatment plant; (4) storage tanks or reservoirs; and (5) a distribution system linking distribution reservoirs with the users. A number of pumping stations are usually needed throughout the system to transport water and maintain desired pressure. Treatment plants can use a wide range of technology, but a typical system might use coarse strainers, aeration fountains to oxidize impurities, fine mesh strainers, sand filters, chlorination stations, and a collection of mixing, metering and pumping stations. Depending on the quality of source water and the demand being met, water treatment can become much more complex. Additional processes might include sedimentation, coagulation and flocculation, and ways to remove color, taste, and odor. For industry, water may have to be softened and demineralized.

When one considers that almost all of the withdrawn water is lifted and pressurized by pumps and that most of it is treated with the processes described above before being distributed through complex networks, it becomes possible to visualize the scope and sophistication of the water system technology upon which we have become so dependent. Operating the modern water system requires the skillful blending of state-of-the-art technology with a host of political, social, legal, economic, and organizational elements. Furthermore, it depends on the continued existence of a support network supplying spare parts, maintenance, chemicals, and electrical power.

Considerable differences exist among water systems in this country. Systems in the West and Southwest have a tendency to be large, centrally operated and managed facilities with considerable excess capacity. The source of water for western systems is commonly Federal facilities and State water projects. For example, the Metropolitan Water District serves cities along the coast of Southern California. The District receives water through aqueducts from Northern California, the Colorado River, and the Owens Valley 185 miles from Los Angeles. Despite the impressive regional systems developed for the Southwest, shortages are projected for many areas by the year 2000 (WRC, 1975).

In the water-rich East, the situation is more fragmented, with local governments typically responsible for their own water needs. Systems tend to be smaller, with few regional ties. For example, in New England, 84 percent of the water systems are municipally owned. Cooperation among these operators is minimal, and they cling to their operating independence. Only recently have extra-local political institutions formed to provide access to remote supplies.

The source of water is also an important consideration in any discussion of water systems. Over 50 percent of the nation's drinking water comes from groundwater and receives little or no treatment other than disinfection. Groundwater sources are vulnerable to chemical spills and contamination from landfills, petroleum storage tanks, and other buried sources. On the other hand, underground sources are less susceptible to the impacts of most enmergencies, for example, flash floods, earthquakes, drought, hurricanes, and tsunamis. Of the systems serving more than 10,000 people each, 38 percent use groundwater as their only source, 27 percent use surface water as their only source, and 16 percent purchase all of their water. Thus, 71 percent of the largest systems in the country depend on a single water source. Single-source systems are at risk from possible contamination, competition from other users, and disruption of flow in transmission systems.

Urbanization represents a serious problem for most water utilities. As this process continues, local supplies of water not only become less and less able to meet the increased demand, but fall prey to construction, contamination, and zoning restrictions (New England River Basins Commission, 1980). Older communities have been forced to reach farther and farther into the surrounding region for additional supplies. As lifelines carrying these supplies are extended, water systems become more dependent on electrical utilities to supply the energy for transporting water over long distances. They also become more reliant on sophisticated monitoring and control technologies for operating the lifelines.

In 1980, of the nation's 229.6 million people, some 87 percent were served by community systems with more than 25 customers. The remainder are rural self-served or very small public systems (Fact Sheet supplied by the American Water Works Association). The following table compares the distribution of community water systems by size with the distribution of the population served by these systems in 1980.

Type of System	Population Served	Number of Systems	Total Population	% of Total Population Served
Small	25-9,999	57,311	34,900,000	17
Medium	10,000 to 99,999	2,516	62,200,000	32
Large	>100,000	273	103,600,000	51
		60,100	200,700,000	100

Source: American Water Works Association

As might be expected, the table shows that the bulk of the domestic water in this country is supplied by community water systems and that a relatively small number of large systems supply most of the total population. This suggests that the preparedness of these comparatively few large systems is of vital interest to the national survival.

It has been estimated that by the year 2000, 90 percent of the population will depend on central or pressurized noncentral systems (WRC, 1975). Because such systems are dependent on electricity for pumping, facility operation, and monitoring, this estimate highlights our dependence on electric power to provide water. In light of the almost universal absence of alternative fossil-fuel-driven pumps or standby generators, most communities would be without water in a few days after losing electrical supply.

In the event of a major power failure, peoples in rural areas could obtain water from shallow wells or nearby surface water, except in arid regions. However, urbanites would be forced to migrate to locations where there were adequate surface or near-surface water supplies once the water they may have stored for themselves or that trapped in the distribution system was gone. Past nuclear attack assessments have generally assumed that power can be restored in a matter of days. We will argue in this report that EMP and other factors make long-term outages of electrical power at least plausible in the event of a nuclear attack. Furthermore, the time needed to restore water sytems in past emergencies has been longer than is generally assumed in the nuclear attack scenarios.

In summary, the evidence suggests that water systems may be more vulnerable than commonly believed. This conclusion is supported by (1) the increasing scale and sophistication of water systems, (2) a dependence on a relatively small number of large systems, (3) the increasing demands and limited access to new supplies, (4) a general lack of alternative sources, (5) increased risk of accidental pollution of sources resulting from an expanding economy and a proliferation of exotic chemicals, (5) increased levels of terrorism to which all large systems are more vulnerable, and (6) an almost total dependence on electic power. The question of vulnerability will be explored further once it is established in the next section that water systems have the potential for being seriously disrupted by disasters.

2. EMERGENCIES AND THE DELIVERY OF WATER

2.1 DO EMERGENCIES AFFECT THE PROVISIONING OF WATER?

Man has been perfecting his skill in managing water for over 5000 years. During this time he has developed skill in directing water, controlling excess flow, reducing the impacts of supply variations through storage, applying water to the production of goods and energy, and removing waste by means of water. Despite the control achieved through technology and a large body of experience, water-related hazards still exist and their economic and health impacts may even be increasing as our population and economy expand (Lindorff, 1977; Cochrane, 1975).

An example of the diversity and pervasiveness of hydrologic hazards is found in the United States Geological Survey's National Water Summary covering 1982 and the first 6 months of 1983 (USGS, 1984). This summary lists some 45 significant hydrologic events which resulted in economic loss or deaths. For instance, in 1982 floods produced over $3 billion worth of property damage and took 100 lives. The events described in the summary include 30 floods, 3 mudslides, 6 localized droughts, 3 chemical spills, 2 sinkholes, and 1 dam failure. While the period was somewhat wetter than usual, the diversity of the water-related impact listed above is not unusual. Thus, it is typical to have floods and droughts occurring in the same year in different parts of the country.

With the exception of earthquakes and drought, the literature reveals that there is limited interest in the problem of water supply during and after disasters. This is in direct contrast to the extensive literature describing the role of water in the hydrologic hazards listed above. References dealing with the provisioning of food in emergencies are more numerous than those dealing with water. One can speculate that this may be due in part to the fact that water is commonly considered a food item in disaster research, even though it is different in almost every aspect of production, distribution, and sales. Emergency water planners themselves do not always distinquish between food and water. For instance, the Emergency Water Administration's Water Emergency Plan (1981) defines food as all commodities or products that can be eaten or drunk.

Another possible reason for the seeming lack of concern with the effects of disasters on water delivery has to do with past experience. Supplying water has not been an insurmountable problem in most past disasters. Water systems routinely respond to temporary outages that do not seriously impair their ability to deliver water. Such outages may be caused by line breaks, equipment failures, human errors, or leaks. While this experience has a positive aspect in that it better prepares the system to respond to serious emergencies, the ability to handle normal outages may induce overconfidence in the resiliency of the system

and may actually inhibit preparedness planning on the part of system operators (White and Haas, 1975).

Schinzinger and Fagin (1979) define two levels of emergencies that may be useful in understanding this reaction. Their definitions reflect the perspective of the water system community and the capacity of typical systems to respond to emergencies. An emergency is deemed to exist when a large service area is expected to be without water for three days or more, or when fewer water users, but users with critical needs, lose service for a prolonged period. A "large" service area is defined by the difficulties encountered in supplying water by alternate means, such as trucking. Critical users are typically institutions such as hospitals, schools used for emergency relief, work places with large numbers of employees, or farmers with crops at a critical stage.

A major emergency is one where substantial outside assistance is required or restoration of service to a majority of users is not expected for at least a week. Outside assistance implies help with water, personnel, or equipment from nearby water systems. Lending assistance may require these systems to reduce their own service and will increase their cost.

In reality, few emergencies have occurred that involve systems of any size experiencing outages that exhausted the 2- to 3-day reserve contained in the typical distribution system. To some extent, we have been lucky in this regard, but also the probability of a given disaster event spatially coinciding with a large water system is fairly small.

2.1.1 The Trenton Example

Low-probability events can and do happen, however, and several examples of water emergencies have been documented in the literature. One of the best known examples concerns the system failure that occurred in Trenton, New Jersey, on August 31, 1975 (Baxter, 1976). In 1975, Trenton served 211,000 people in the city and surrounding townships plus a number of industries. The highest monthly consumption in 1974 was 1.2 billion gal./d and the highest daily consumption 40 million gal./d. At the time of the failure, Trenton had four major pumps in a single pump house, and the rated capacity ranged from 10 to 25 million gal./d. The source of its water was the Delaware River, and water taken directly from the river was placed in the reservoir. The reservoir held 90 million gallons, a 3-day supply.

The accident occurred when a hydraulic control system failed while some of the pumps were being switched. The ensuing sequence of events caused the pump house to be flooded to a depth of 12 feet. The flood water, in turn, caused a structural failure of a conduit between the filters and the clearwell. This failure went undetected for many hours, delaying recognition of the seriousness of the problem to the total system. As a result,

the decision was made that reserves were adequate to meet the emergency without curtailing consumption. As word of the problem spread, however, water hoarding became common, and large demands were placed on the remaining reserve in the reservoir. Poor communication between system technical staff and the mayor's office further delayed needed emergency proclamations. When the proclamations finally came, the reservoir was dangerously low, system pressure had been reduced, and some areas had no water whatsoever.

Before the system was restored, the city was without adequate water supply for one week. In fact, parts of the city were supplied water by tank truck while the remainder had abnormally low flow. Most help was supplied by neighboring communities. Some 700 men used 90 fire trucks and 18 miles of hose to pump water directly into Trenton's hydrants. Even this effort only delivered 11 million gal./d of filtered, chlorinated water to the fire hydrants at the extremities of the system. As the week progressed, the fire trucks and hoses were gradually replaced by pipes and pumps from civil defense stockpiles. However, some of the sources discontinued supplying water due to severe stresses placed on their own systems. At the height of the crisis, local industry was forced to lay off almost 40,000 workers.

The Trenton example shows that simple equipment failures can seriously cripple a system when enough attention is not given to preparedness planning. Schinzinger and Fagin (1979) point out the following deficiencies in Trenton's water system preparedness:

1. A number of physical shortcomings existed in the plant as the result of cost cutting. Examples included the lack of proper interlocks with the pump motors and the lack of permanent interconnections to adjacent water agencies.

2. The professionals in the water works did not have a strong voice in the budget process and were unable to obtain sufficient funds for needed repairs, maintenance, and staff development. Their advocate, the Director of Public Works, was a political appointee with little experience in water purveying.

3. Workers had received no emergency training and had no clear understanding of their roles and responsibilities in the event of an emergency. They were dependent upon supervisory personnel for direction.

4. Disaster planning was almost nonexistent. Critical users of the system had not been identified. Communication procedures had not been determined and policy criteria for determining the extent and duration of various emergencies had not been formulated. Contingency contracts for repair services had not been put in place.

The deficiencies noted are not unique to this isolated case but are present to some degree in most systems. Older and small-

er systems are most likely to be inadequately prepared for emergencies. Even where emergency plans have been created, they may still be largely unimplemented and untested. It is obvious that the impact of the emergency on Trenton was lessened considerably by help from surrounding communities. In fact, Trenton even obtained assistance from experienced technical personnel from nearby communities and from the engineering firm that designed their plant. One cannot help but wonder what the impact would have been if regional resources had not been so readily available, as would be the case in the event of nuclear attack.

2.1.2 The San Fernando Example

Some of the best prepared water systems are in the large metropolitan areas found in the earthquake-prone regions of California. Only California and Massachusetts are actively pursuing the improvement of their building codes to strengthen water facilities against ground movement, and most of this activity is focused on two cities, Los Angeles and Long Beach (Ayre, 1975). Despite "hardening" and better emergency planning, California cities can still be severely impacted by disasters, as evidenced by the earthquake that hit San Fernando in February of 1971. The quake was moderate, measuring only 6.6 on the Richter scale, but the damage was extensive -- 363 breaks in mains, altogether about 1500 leaks, and damage to 25 facilities including treatment, pressure control, and pumping plants. The Van Norman Dam complex was severly shaken, causing the lowering of its reservoir and the evacuation of 80,000 people from the potential inundation area. Damage was estimated at $500 million, and more than 60 lives were lost.

As in the case of Trenton, surrounding communities and various governmental agencies were called upon to help. Seventy-five tank trucks were put into service transporting potable water. Some were rented, many were loaned by brewers, soft drink bottlers, and spring water distributors. The National Guard provided 35 two-wheeled tank trailers, suitably sterilized, for provisioning water for schools in the affected area. Twenty Los Angeles Fire Department pumpers transferred water via fire hydrants. Emergency connections were made to the sources in the city of Los Angeles and the Metropolitan Water District. The Corps of Engineers assisted in installing a temporary aboveground distribution system with garden hose connectors for household services and 2-1/2-in. outlets as fire hydrants.

Even with the tremendous resources available to this relatively small city of 18,000 from its much larger neighbors, San Fernando's water supply shortages were still significant. Parts of the city were without water for the first four to twelve days, and the city was unable to use any of its wells until nine months later.

Trenton and San Fernando are good examples of disaster situations in that they allow the comparison of the impacts of

short-term and long-term emergencies, the impacts on large and small cities, and the impacts on a relatively poorly prepared city, Trenton, and a much better prepared city, San Fernando. More examples could be cited, but it should be apparent from these two very different examples that disasters can incapacitate water systems and that provisioning water in an emergency can demand extraordinary effort and produce significant secondary impacts such as increased stress and unemployment.

2.2 WATER SYSTEMS AND NUCLEAR ATTACK

Of the various situations inducing water emergencies, a national emergency resulting from a nuclear attack unquestionably will have the most serious consequences. For this reason, references to provisioning water in the civil defense literature are examined in some detail in this section. Furthermore, FEMA has been assigned the lead responsibility in national emergency civil preparedness. This includes planning for the direction of governmental, economic, and other activities of the Federal government and providing for the necessary direction and assistance to State and local governments for the national civil defense programs. Much of the past research in civil defense has been funded by FEMA or its predecessors; therefore, it is of some interest to review the references to emergency water in the civil defense literature.

As will be shown below, there are very few references to emergency water in the civil defense literature, and most references reflect an underlying assumption that provisioning water does not constitute a serious problem for host areas or for recovery in the postattack environment.

An example of most typical early documents dealing with provisioning water is the handbook developed jointly by the Office of Civil Defense, the Red Cross, and the Welfare Administration (Office of Civil Defense, 1966). In it, individual water requirements are defined, and procedures for dispensing and disinfecting water are described. The concern is for sheltering the population, and since water is prestored for shelter occupants, water systems are not vital to this concern.

A second research topic dealing directly with water systems also appears in the early literature. An example of this work is a set of guidelines for use by waterworks utilities in disaster control planning (Office of Civil Defense, 1964). The guidelines recommend a set of nuclear attack preparedness adjustments that are quite sound. A follow-up study outlined a comprehensive survey form that could be used to determine the preparedness of individual utilities (Public Health Service, 1966). The author states that reviewers felt that the form was too detailed and should be simplified. This would probably always be the reaction to an attempt to ascertain the preparedness of a complex system through a mail survey. The survey does not appear to have been

accomplished. Had it been, data on the general preparedness of water systems would now be available.

A third topic, assessments of the impacts of nuclear war on utilities, appeared in the literature around 1970. In a series of three assessments, Goodrich (1967) and Nevin (1969, 1970) estimated the impact on water systems in San Jose, Albuquerque, and Detroit from a single hypothetical nuclear burst of five megatons. The studies generally found that extensive damage was caused by the burst. In the Albuquerque simulation, it was found that the ground shock would have been sufficient to cause ruptures between surface reservoirs and underground mains over at least 50 percent of the city, and to cause leakage at some services throughout most of the city. Some 16 of the 30 reservoirs would have been completely destroyed. Even with the assumption that reservoir outlets were promptly closed, the loss of reservoir water totaled 20 million gallons of the 37 million gallons stored.

Despite the magnitude of damage recorded by these studies, they generally conclude that the water systems were able to meet the survival needs of the population. This series of studies may explain why later civil defense literature either does not address impacts to water systems or dismisses these impacts with only cursory analysis. The reasoning followed by Haaland (1974) in analyzing the water situation for relocated populations is a good example of how the civil defense community has treated the problem of water supply in recent years. He begins by stating that most areas designated as reception areas have abundant water sources. He concludes that an adequate supply of drinking water will exist as long as reductions in bathing and washing are assumed. Difficulties in restoring normal service are not discussed.

The analyses performed in past assessments are seriously flawed in that they overlook many potential vulnerabilities of water sources and water systems. It is only necessary to mention a few of these potential problems to see that broader analysis is required to reach meaningful conclusions about the availability of water in a general nuclear attack.

1. Single-weapon, single-city studies fail to consider cumulative effects. For instance, it is assumed regional supplies of water or electricity will be available to make up for some of the shortage caused by the nuclear burst. Yet most planning guidelines assume that utilities will have to make do with their own resoures at least for the first 30 days after an attack (Emergency Water Administration, 1981). Haaland (1974) says that electrical power may be out for many weeks because of downed transmission lines and that 50 percent of the power plants will be destroyed in a general war scenario. When one considers the drain imposed on regional resources by the relatively minor Trenton water emergency, it should be apparent that local systems can expect little help from

neighboring areas which may be without communication and power and forced to accommodate survivors from the target community. An analysis based on the detonation of a single weapon may be unrealistic since the advent of multiple warhead weapons and increased accuracy. Katz (1982) points out the tactical advantages of a triangular pattern of blasts which produces significantly more damage. It may be more realistic to use this pattern in assessing the vulnerabilities of the systems in a given community.

2. The impact of nuclear Electromagnetic Pulse (EMP) was either ignored or assumed to be negligible in the assessment studies. Continued concern with possible EMP impacts is reflected in current research (Barnes, 1984). This concern is at least partially triggered by the increasing dependence on electronics in utility control and monitoring systems.

   Barnes (1984) describes EMP in the following manner. EMP is a transient electromagnetic pulse of high-intensity electromagnetic fields caused by a nuclear detonation at high altitudes. These intense fields induce voltage and current spikes in electrical conductors. A single high-altitude burst may subject most of the continental United States to EMP on the order of tens of kV/meter. Surges would be induced by EMP in transmission and distribution circuits and in control and communication elements in electrical power systems throughout the electric network. Such widespread disturbances could upset the stability of electrical energy systems and result in massive power failure. The impact of EMP is much like lightning, though normal lightning protection may be ineffective against EMP because it does not respond quickly enough to the fast rise of the pulse.

   A number of electrical components are susceptible to damage from EMP. Spike surges can capacitively couple across transformers and propagate to generators or motors where it can puncture insulation. Digital control circuits are particularly susceptible to spikes because these circuits cannot distinguish a legitimate signal pulse from a spurious pulse that provides the same electrical impulse. Finally, components can be damaged by the magnitude of the current accompanying the pulse.

   There are two possible forms of EMP impact on water systems. The electrical power on which water systems are almost totally dependent can be disrupted and direct damage can be sustained by pump motors and control and monitoring circuits. At the present time, almost no protection from EMP is in place.

   EMP carries implications for the vulnerability of water systems that must be factored into future vulnerability assessments. If EMP can deliver the damage implied by recent research, one must accept a situation in which hundreds or thousands of water systems will require replacement components of a manufacturing and support network that is itself impaired,

clearly a situation which could not be satisfied in months, perhaps years. Furthermore, these demands would come at a time when defense needs would carry higher priorities.

3. The assessments almost totally ignore the consequences of social disruption caused by a nuclear attack. Katz (1982) reviews what is known about this subject and summarizes the experience of populations subjected to bombing in World War II. In the aftermath of intense bombing, signs of organization breakdown, confusion, decreased productivity, and resistance to needed adjustments developed. People were increasingly concerned about immediate and personal aims rather than national objectives.

   A nuclear attack would be worse then World War II bombings because of unfamiliar radiation hazards and many more sick and dying people. Despite this, past assessments have assumed that waterworks employees will faithfully and efficiently go about restoring the system. The threat of unsurveyed radioactive hot spots, the fear of fallout, and many impediments including obliterated landmarks, blocked roadways, fires, and debris will severely limit the ability of waterworks crews to assess damage, locate and close hundreds of valves to save water, and restore service.

   In the case of the San Francisco earthquake, shutting off broken service mains and house supply pipes proved to be the most serious problem in rehabilitating the city distribution system. This task will be even more difficult in the event of nuclear attack because crews will be limited in the number of hours they can work outside each day due to radiation exposure. For instance, at the relatively low outside dose rate of 2 to 10 R/hr, activities must be limited to less than one hour per day (Haaland, 1974). Even if the system could be rebuilt with short bursts of activity, psychological factors such as concern for family members and personal survival will still act to reduce the effectiveness of work crews. Though difficult to predict, the impacts of reduced effectiveness of the individuals expected to restore water systems must be factored into any realistic assessment of system vulnerability.

4. Several studies have shown that contamination of water supplies by radioactive fallout will not significantly increase the number of fatalities (Office of Civil Defense, 1965; Jensen, 1967). However, contamination of surface- and groundwater from toxic chemical spills in a nuclear attack might pose a threat to survivors and impact the local water systems. No research on this subject was found.

5. The phenomenon of Nuclear Winter has only recently been hypothesized (Turco, 1983). A consensus on the magnitude of climatic alternation is not likely to be reached for some time, however, the initial scenarios predicted severe temperature reductions lasting a number of months following a general nuclear attack. Abnormal temperature reductions have

always meant problems for water systems. For instance, the winter of 1976-1977 produced a high incidence of freezing and line ruptures in many U.S. cities (Pavia and Thomas, 1977). To make matters worst, problems from a single low temperature incident do not all appear immediately but continue to show up over weeks or months. Nuclear Winter could thus impose a continuous burden during the restoration period. Impacts of freezing temperatures will be particularly severe in southern cities with shallow distribution systems.

Recent work on Nuclear Winter suggests yet another impact to water systems, the possibility of extended drought for major portions of the U.S. Previous discussions demonstrated the vulnerability of large urban systems to extended drought. It is possible that the final consensus on the impact of Nuclear Winter will produce somewhat less impact than initially predicted, but water systems will nonetheless merit additional study.

6. Water treatment and waste treatment plants are dependent on the use of large quantities of chemicals in their respective processes. No assessments of current inventories or postattack availability of these chemicals appeared in the literature reviewed. A crisis relocation guide for sewage treatment operators published in 1979 (Defense Civil Preparedness Agency, 1979) describes a check made of the chlorine supplies of four waste treatment plants in the San Francisco area. These plants represented the major types of treatment processes in use today. The surveyors found that supplies on hand were adequate for only 1 to 3.4 days for the host area population load used in the study, three times the normal population. Operators indicated that they are reluctant to store more than a few days' supply of chlorine because of the hazards associated with the volatile chemical and the cost of demurrage charges for chlorine cylinders. These findings can probably be extrapolated to the general population of treatment plants.

Few documents published in the civil defense field in recent years discuss water systems. An exception is the guide mentioned above for host area waste treatment facility operators that contains procedures for (1) estimating increased loading produced by evacuees and (2) identifying the process steps most likely to fail from shock loads or overloads. Of the four plants on which the procedures were simulated, three would have experienced extreme problems in handling the relocated population which was only three times the size of the existing population. At two of the plants, a complete loss of treatment in the trickling filters would have occurred. In the third plant, hydraulic overloads would have occurred in both the primary and secondary clarifiers. Only the fourth plant would have had little trouble in accommodating the increased load. This was due in part to the plant being overdesigned to accommodate future growth.

It is interesting to compare these results with the total absence of concern for capacity limitations on host area water and waste systems in the guidance for reception and care planning for host communities (Defense Civil Preparedness Agency, 1977). The only references to water found in this document are instructions to check utility plans and to maintain adequate water supply. It is not clear as to how this is to be done. There is no mention of waste treatment facilities.

Evacuation plans reviewed for this assessment do not contain special assessments of water or waste capability, and it is doubtful whether much analysis of this type has been done. The integrated plans, now the focus of FEMA disaster planning, are based on State vulnerabilty analyses. A review of a number of these analyses (examples include Utah Office of Emergency Services, 1976 and Wisconsin Division of Emergency Government, 1981) show that they contain descriptions of the disaster types likely to occur in the State and say nothing about the vulnerability of various urban systems.

The discussion above should clearly demonstrate that a lack of appreciation of the vulnerability of water systems in national emergencies exists. Research in this area is overdue.

3. THE VULNERABILITY OF WATER SYSTEMS

The state of preparedness of this country's water systems for the wide range of possible disasters is not known. We have argued that most water systems respond effectively to limited emergencies, but can be overwhelmed by major emergencies that cause significant loss of capacity or excessive demand. A nuclear attack would undoubtedly result in major emergencies in large urban areas and perhaps in host areas following relocation. Of all the possible natural disasters, earthquakes have the greatest potential for causing major water emergencies. Earthquakes are actually anticipated that will be more destructive than the San Francisco earthquake of 1906. It is estimated that a major earthquake in Los Angeles alone could do as much as $50 billion in damage, of which half would be utility damage (Ayre, 1975). Experts also believe that a major earthquake in a large metropolitan area could easily produce more loss than the total historic dollar damage of past quakes (Ayre, 1975). Such estimates reflect the population growth and resultant construction that has occurred in metropolitan areas since the time of the San Francisco earthquake.

In this section we will summarize the major factors, most of which have been discussed previously, that tend to increase the vulnerability of water systems. Vulnerability or the probability that a disaster will produce a water emergency should be a primary concern of emergency preparedness planners. We will also summarize a set of adjustments that are useful in minimizing the impact of the vulnerability factors. Table 1 lists the various factors and adjustments organized by supply, demand, technology, operations, and nuclear attack. It is impossible to judge from the existing literature if these adjustments have been implemented to the extent that overall vulnerability has remained constant or, hopefully, even decreased. The limited data available plus circumstantial and anecdotal evidence suggest that system managers will have an increasingly difficult time in reducing vulnerability in the future.

3.1 SUPPLY

The demand for water in urban areas increased 13.5 percent from 1970-1975, while supplies increased only about 6 percent (New England River Basins Commission, 1980). Thus, capacity is not keeping up with continued increase in withdrawals. This suggests a continuing decrease in the reliability of water delivery, that is, a greater chance for supply deficiences. Deficiencies, in turn, can force rationing with its associated economic losses and can increase the probability that "normal" outages will trigger water emergencies.

A major reason for the failure of water systems to track increased demand is their inability to locate and develop new sources of supply. Competition for land for recreation, agricul-

Table 1. Summary list of factors increasing water system vulnerability.

Factors increasing vulnerability	Adjustments to minimize vulnerability
<u>Supply</u>	
Increase competition for existing source, threat of lawsuits or adjudication	Develop alternative sources, promote conservation, have water rights defined, develop storage, reuse water, desalinate water
Inadequate local supply for expansion or dependence on single source	Same
Difficulty in finding new sources--resistance, legal constraints, etc.	Have laws changed, develop regional compacts, negotiate with environmentalists
Pollution of water source	Monitor source, develop alternate sources
Threat of climatic change--reduced precipitation	Monitor trends, project future conditions, increase storage
Increased distance to source--longer lifelines	Promote conservation, reuse water redundant pipelines, better monitoring and security, standby generators
<u>Demand</u>	
Trend of increasing per capita use	Promote conservation, educate public, price water adequately
Increased demand from unexpected change in lifestyle, farming practice, technology	Promote conservation, change price mechanism, monitor change
Increased regulation--fire protection, environmental laws, health standard	Anticipate requirements, put mechanisms in place to be able to raise needed capital and revenue

Table 1. (Continued)

Factors increasing vulnerability	Adjustments to minimize vulnerability
Technology	
Increased system complexity	Harden system components, use standardized components, break system into semi-independent systems, develop network analysis capability and emergency plans
Increased system sophistication	Train staff, develop contracts for support (equipment and experts), use standardized components, modularize
Lack of redundancy in pipelines, components	Develop redundant networks and components, maintain inventory of spare components
Dependence on electrical power	Install standby generators
Operations	
Difficulty in raising capital	Remove organizational constraints. educate decision makers
Inappropriate pricing mechanisms	Change mechanism
Inattention to emergency planning or training	Promote better construction codes, better code enforcement, emergency planning, exercises, vulnerability analysis, identify critical users, know demand patterns
Lack of mutual aid agreements or interconnections	Enter into support agreement
Increased threat from terrorism	Improve surveillance and develop response plan

Table 1. (Continued)

Factors increasing vulnerability	Adjustments to Minimize vulnerability
Nuclear Attack	
EMP	Shield system, add arrestors
Loss of key personnel and reduced productivity	Train extra people, develop plans and shelters
Nuclear Winter	Protect system against freezing, conservation plans
Absence of regional assistance	Develop stand-alone capability
Shortages in chemicals and replacement components	Create inventory of critical resources
Loss of electricity	Install standby generators

ture, flood control, and energy production has reduced the number of sites available for water supply development, and attempts to develop sites in conjunctive use take a long time, increasing the chances of a critical situation before the next increment of supply is on-line. An example of the difficulty in acquiring sites is reflected in the decrease in the growth of reservoir capacity since the 1960s. This has occurred because cost effective dam sites, those having a large capacity per unit volume of dam, have been largely utilized or dedicated to other uses (USGS, 1984).

As easily exploited water resources are developed, the cost of developing the remaining resources rises steeply. Artifically low prices for water make it difficult to raise the capital needed for expansion without governmental help.

Developing new supplies is a particularly serious problem with the municipal systems in older parts of the country. A survey of New England systems found that 31 percent of the respondents had water shortages over the preceding five years. Of these, drought triggered shortages in 45 percent and increased use triggered shortages in 50 percent (New England River Basins Commission, 1980).

Maintenance and renovation needs uncovered as the result of a review initiated in 1984 for the 90-year-old water supply system of Portland, Oregon are typical of many older systems (The Oregonian, 1985). It was determined that the Mount Tabor Reservoir No. 6 dike might fail in a major earthquake; the system's eight elevated water tanks were in need of analysis and repairs; and 10 concrete tanks had structural problems, one so seriously damaged that it was abandoned in September 1984. Pipe mains that developed 18 breaks in 1958 sprung 48 leaks in both 1983 and 1984. Thus the number of breaks per mile of pipe main more than doubled in 25 years. The cost to repair these deficiencies was estimated to be "several million dollars."

Even more significant than this cost is the fact that reduced water volumes in the reservoir and tanks will require special measures to ensure uninterrupted water services. For example, until repairs are completed, Water Bureau workers will be forced to monitor fire calls and immediately pump water into nearby elevated tanks, a procedure that will add an estimated $20,000 to Bureau's electricity bill according to a Bureau official. The same official is quoted by The Oregonian as saying, "We have a system that's 90 years old, and it takes a lot of vigilance and a lot of care to keep something that old operational."

As systems approach safe yield (the amount of water that can be withdrawn or released on an ongoing basis with an acceptably small risk of supply interruption), they become more sensitive to seasonal drought. This is as true of large systems as it is of small systems. A review of the history of the New York City water system between 1900 and 1970 showed periodic shortages necessitating conservation programs every 18 years. These shortages were caused by drought or systems yield. The drought of 1965 forced reductions of 20 percent (Overman, 1969).

The water shortage of 1977 in the Washington, D.C., metropolitan area prompted the formation of a regional task force to study the water supply situation (Hooker, 1980). A two-year effort followed, resulting in a unique agreement among local governments on conservation measures to be placed in effect in the event of future shortages. The agreement is only a partial solution, however, to a continuing supply problem affecting the metropolitan area. Approximately three quarters of the 3 million Metropolitan Washington residents are dependent on the Potomac River for their water supply. Unfortunately, the Potomac is not a reliable source of water because its flow is primarily a function of rainfall and can be greatly reduced by the one- or two-year droughts that periodically occur in the East. The recorded low flow for the river is 388 million gal./d. Withdrawals have exceeded this level 41 times since 1971. Storage and distribution system limitations of metropolitan water suppliers only compound the problem since many of them have less than a one-day reserve of water.

Other problems facing water systems include pollution of sources, droughts or long-term changes in climate, and increased length of lifelines. Viessman (1985) feels that treatment of polluted waters is perhaps the greatest challenge in water-supply engineering. Furthermore, pollution can be episodic, endangering the source of local supply, and causing water emergencies. For example, serious pollution of a major water supply recently occurred in Fredericksburg, Va., when an oil pipeline ruptured, dumping thousands of gallons of fuel into the Rappahannock River (Hooker, 1980).

A few metropolitan areas including Long Island, Tucson, and Miami rely exclusively on groundwater from extensive nearby aquifers. They are especially vulnerable to contamination of their supplies. At present estimates, man-made pollution corrupts only one percent of the groundwater; unfortunately, the sites of pollution tend to occur in populated regions so that more than one percent of the potentially useful supplies of groundwater are threatened. Much of the pollution stems from 15,000 sanitary landfills that are allowed to accept toxic wastes from small quantity generators -- some four million tons a year. Monitoring is still very poor at these sites, and before the extent of pollution is known, undoubtedly many people will be exposed to unacceptable levels of toxic pollution and many water supplies rendered useless. The slow transit time of chemicals through the groundwater means that some aquifers could remain polluted for hundreds of years.

The most cost-effective adjustments to problems of securing supply are developing alternative sources, securing water rights, improving the management of existing facilities, and promoting conservation. These adjustments tend to be long lead time solutions requiring institutional adjustments, extensive negotiations, and education of decision makers and the public.

3.2 DEMAND

Historically, water policy and programs have focused on supply and ignored demand with the result that water wastage is high and per capita use is increasing. Irrigation is an example of an inefficient water use that has increased consumption rapidly in recent years. The average efficiency of irrigation is only 50 percent while 70 percent is feasible. The result of demand trends has been that prudent reserve capacities have been dissipated quickly and water systems have had to seek new sources before their planning horizons dictated.

The problems of excessive demand caused by increased consumption or regulatory changes require close monitoring and skill in projecting demand. If demand becomes excessive before new supplies are brought on-line, it may be necessary to introduce conservation or rationing programs or to change the pricing mechanism so that the price can reflect the relative scarcity of water. This would require a demand approach to water provision-

ing as opposed to the supply approach presently in effect in most systems.

3.3 TECHNOLOGY

Increased scale of operation and technological innovation have created sophisticated systems demanding highly trained operators. The Three Mile Island incident has shown that mandated training programs are not sufficient to guarantee adequate response in emergency situations. Additional adjustments are needed to reduce risk.

Another attribute of sophisticated systems is increased interpendencies among the various components. Thus, if one portion of the system fails, it may mean the whole system must be brought down because of the inability of the remaining components to accept large deviations in operating paramenters. This is particularly serious in light of increaased threats from terrorism.

It is impossible to guard against all failures, but there are a number of documented design elements and operating procedures that can increase reliability and "harden" a system against potentially disastrous events (Schinzinger and Fagin, 1979). These include standby generators; distribution system redundancy; hardened components able to withstand shock, temperature, EMP transients, and pressure; standardized components; a modularized system; and network analysis capability.

These adjustments require dedication to the principle of preparedness and to the commitment of funds to support staff involvement and equipment procurement. The major factor limiting greater preparedness of water systems is cost. An agency's commitment to preparedness is readily measured by the willingness to budget for such activities and to carry financial reserves to meet emergency needs. Since these activities must be funded from current revenues and revenues are derived from politically sensitive water rates, there is constant pressure to eliminate costs of protection from low risk events. Furthermore, system managers are generally conducting one or more "campaigns" for additional funds at any time and may be unwilling to divert attention from these basic concerns. Managers must seek money for such things as system renovation, system expansion, or the legal requirement to upgrade the system to meet new water quality standards. Because emergency planning has long been a secondary concern, no system has adopted all of the major disaster adjustments recognized as effective, and only a few of the larger systems have made preparedness a system goal. Interestingly, preparedness planning appears to be a function of system size, meaning that small systems tend to be more vulnerable to disruption and even total failure.

3.4 OPERATIONS

The state of a system's preparedness is determined by the extent to which it can adapt to a disruption by putting standby equipment into service, by instituting emergency procedures for the allocation of water, and by restoring service temporarily and permanently. These are operational aspects and require a set of adjustments that include emergency plans, access to repair parts, procedures for switching the system over to an emergency mode of operation without undue loss of time, mutual aid agreements, yearly emergency drills, and training. The large number of parameters that describe a given system, its customers, and the emergency threats faced by the system, preclude standardizing preparedness planning and adjustments at the national level. A unique emergency preparedness plan must be tailored for each system.

A number of institutional and behavioral constraints work against effecting useful adjustments and are difficult to overcome, especially for waterworks managers with engineering backgrounds and limited experience in dealing with such "soft" factors.

Once a disruptive event has occurred, the water system has three primary tasks: to assess the nature and extent of damage, to plan the restoration of service, and to carry out the plan. These activities rely heavily on the resources developed in the preparedness period preceding the event such as guidelines, background data, negotiated support agreements, and staff training.

When threats to equipment and life have been controlled, an assessment of the location and seriousness of each problem must be completed as quickly as possible. A preliminary estimate of resources and the time needed to correct the problem must be accomplished to initiate restoration planning. This estimate must be followed by more careful assessment at a later time. Both the quantity of water that can be handled by the system (i.e., rate of delivery) and the quality of the water (i.e., usability) must be ascertained as quickly as possible. A decision to declare an emergency can then be made.

Restoration planning consists of scheduling resources to complete a series of restoration tasks. Establishing the priority of tasks is an optimization problem that can be quite complex, perhaps best accomplished with one of the many resource allocation models described in the literature. For example, Schinzinger and Fagin (1979) suggest a model that allocates available resources to a predetermined, ordinally ordered priority list. Whatever procedure is used, resources available for restoration work should be assigned using multiple criteria such as required fire flow or critical use by hospitals while staying within the operating constraints imposed by the system in the form of rates of flow, head, and storage capacity. In addition, the system planners have to choose from multiple strategies that include water trucking, evacuation of water users, and repair.

Plan implementation is similar to the normal activities of the system except that interactions with the public, government regulators, and s pport organizations are more frequent and more intense. A great deal of effort goes into procuring emergency equipment, loans, and grants. It would seem logical for water systems to use restoration planning and implemention as a means of effecting desired system improvements that reduce the risk of future disasters or capture other benefits. Unfortunately, the press of time and natural desire to reestablish predisaster stability usually preclude such improvements. All too often, restoration decisions are based on the exigencies of the moment, public and political pressures (for the rapid restoration of a vote or tax base), or on a hodgepodge of programs and traditional policies (White and Haas, 1975).

3.5 NUCLEAR ATTACK

The vulnerabilty of water systems in nuclear attack has been discussed previously in some detail and requires no additional discussion except to add that the adjustments listed in Table 1 are very costly, and most system operators are unlikely to feel the risk justifies such cost unless other disasters with similar impacts such as earthquakes are a threat.

Balancing risk against the cost of preparedness adjustments is the responsibility of system managers. The equation must be uniquely constructed for each system since vulnerability is a function of the threats faced, their likelihood of occurrence, the configuration of the system, the needs of critical users, past history, the present state of preparedness, the availability of funds, and the social setting. Furthermore, the concept of risk management is still evolving, and there is a broad spectrum of views in the utility community about what constitutes acceptable risk. Regulators and public interest groups will help define acceptable risk as time goes on. In the meantime, the emergency management community should be concerned whether water systems are becoming more vulnerable as waterworks managers attempt to counter the many factors increasing system vulnerability with limited resources. Additionally, the consideration of disaster impacts on local waterworks should be emphasized more heavily in emergency planning, with particular attention to the support and resources needed to restore near- normal capacity postdisaster. Until this happens, other recovery activities such as putting people back to work really cannot begin. Planning should address such issues as the availability of and access to emergency equipment and regional support agreements among water systems. These ideas will reappear in the research recommendations, but first it will be of value to describe the help available to local water utilities in the event of an emergency.

4. RESPONSIBILITIES FOR WATER PROVISIONING

The mechanism that has been created for delivering governmental assistance to the local water utility in the event of an emergency is a complex hierarchy of relationships for which responsibilities are still evolving. It is useful to review the mechanism as it exists today because it will help to support the research needs identified in the next section of this assessment and because it reveals programmatic areas within FEMA which should be concerned with provisioning of emergency water.

The primary responsibility for providing water in the event of an emergency lies with the local public or private water system. If the system lacks sufficient resources to accomplish this task, it can appeal for support to the State government or directly to the Federal agency responsible for the particular form of assistance needed. Various levels of civil emergencies exist. In State declared and non-State declared emergencies, no special Federal assistance is available, and entities in need of assistance must compete for funds from ongoing programs. If the governor petitions for and the President declares an area to be a major disaster area, then it becomes eligible for special grants, loans, and other forms of disaster support from Federal agencies. The State normally sets priorities, makes allocations of water and water support, and acts as an advocate for local entities to the Federal agencies for support claims.

The preparedness function of the Federal agencies in civil emergencies is to furnish States and local entities technical advice and information and assist them in establishing emergency water programs. The emergency response function of the Federal agencies in civil emergencies is to render such assistance as authorized by statute or Presidential directive to those local entities and States unable to manage (normally to finance) the declared emergency and to those who request assistance.

National emergencies have more serious implications for water provisioning than civil emergencies. They are declared by the President or by concurrent resolution of the Congress if either of them finds that an attack upon the United States has occurred or is anticipated. The Federal government plays a bigger role in national emergencies than it does in the civil emergencies. In national emergencies, priorities for the allocation of water resources and support would be invoked by the Federal resource agencies that place defense and critical industries, including agriculture at certain points in the growing cycle, ahead of the general needs of the population. Federal agencies designated as resource agencies, coordinated by FEMA and led by the U.S. Army Corps of Engineers, would issue directives and effect control of water resources and facilities as necessary to accomplish the goals of defense and survival.

To ensure continuity, the roles of Federal agencies in water emergencies are extensions of their essential functions as they

relate to water, water support requirements, and environmental programs. This logical extension of functions allows State and local entities to solicit assistance through normal channels, ensuring better communication and response and is reflected in the agreements now being worked out as a logical complement to Executive Order 11490 which assigns general emergency preparedness functions to Federal departments and agencies. The following list is a summary of these functions and cognizant resource agencies.

1. Environmental Protection Agency (EPA). The EPA is responsible for developing plans, programs, and guidance regarding drinking water; the providing of emergency community water supplies; safeguarding water quality; and acting as claimant for material and equipment requirements for water supply and waste water systems. Thus local water systems or the State representing their interest turn to the EPA for Federal assistance. The EPA has not created published guidelines for waste system emergency plans that are required for Federal construction grants and expects the States with primacy to certify the adequacy of such plans.

2. The Department of the Interior (DOI). The DOI is responsible for collecting and disseminating water resource data and information. It develops plans, programs, and guidance for operation of irrigation and multipurpose water supply facilities under its jurisdiction. It negotiates and adjudicates Indian water rights.

3. The Department of Commerce (DOC). The DOC is responsible for developing plans, programs, and guidance for building new water facilities after an emergency and for supplying water to critical industries. It also acts as a claimant for the industrial sector and issues priority rating authorizations for water support resources for programs approved by the USACE within FEMA allowance.

4. The Department of Agriculture (USDA). The USDA is responsible for developing plans, programs, and guidance for water to be used in agricultural production and food processing in an emergency.

5. The Department of Housing and Urban Development (HUD). HUD is responsible for developing criteria for designing and locating housing and community facilities needed during emergencies. It also develops plans for the restoration of community facilities through repair or new construction.

6. The Department of State (DOS). DOS is responsible for making joint water-use arrangements with Canada and Mexico.

7. The Department of Health and Human Services (HHS). HHS is responsible for programs to prevent adverse health effects from biologically or chemically contaminated water. It also

develops contingency plans for water contaminated by radioactivity.

8. The Tennessee Valley Authority (TVA). The TVA is responsible for developing plans and programs for flood control, navigation, and operation of impoundments and other water facilities within the Authority's area of jurisdiction.

9. The Department of Energy (DOE). The DOE develops preparedness plans for electric power.

10. The Department of Transportation (DOT). The DOT arranges for transportation of essential water support supplies.

11. The U.S. Army Corps of Engineers (USACE). The USACE is the lead Federal agency responsible for emergency water. It provides guidance to and coordinates the emergency water planning efforts of other Federal departments and agencies. It also coordinates emergency water planning with State and local entities. It acts as the focal point in the Federal government for the resolution of water resource and support claims that are not resolved at the State or Federal agency level. To aid this process, the USACE will develop priorities, allocations systems, and claimancy procedures.

12. The Federal Emergency Management Agency (FEMA). FEMA coordinates Federal preparedness and response to emergencies. Its responsibilities are quite varied, ranging from policy setting to implementation. Thus, FEMA participates in diverse activities ranging from developing policy guidance for Federal departments and agencies to ensure continuity-of-government to developing a contingency plan for the Olympics. Emergency water is not a primary concern to FEMA in its coordinating role except for its interest in maintaining a general awareness of the preparedness programs of other Federal agencies. Other responsibilities potentially affecting provisioning of water include resolving appealed claimancy disputes between Federal agencies and maintaining stockpiles of critical materiel which could be allocated to facilitate the restoration of water systems in a national emergency.

    FEMA does have, however, considerable interest in promoting water system preparedness and response capability in many of its specific programs and interest areas. Chief among these are the National Earthquake Hazards Reduction Program; Hurricane Preparedness Planning; Civil Defense, including protection of industrial capability; and Fire Prevention. In each of these areas, water systems are threathened by disaster or play a vital role in the well being of the population or the restoration of the community.

    Most of FEMA's programmatic interests are integrated through its integrated Emergency Management activities through which local and State level emergency management programs are funded. The system is described in FEMA guidelines for identifying

hazards, assessing capabilities, setting priorities, and scheduling activities to improve capability over time (FEMA, 1985a and 1985b).

5. RECOMMENDATIONS FOR PROGRAM IMPROVEMENTS AND FUTURE RESEARCH

Using available literature as a base, the general understanding of the problem of provisioning water during emergencies has been assessed in previous sections of this report. A number of deficiencies in this understanding have been pointed out. Furthermore, a review of documents produced by FEMA and its predecessors reveal limited concern for provisioning water and the use of questionable assumptions in past impact assessments and in guidance documents supplied to the States. This section suggests programmatic improvements and research that should help to correct the problems noted above by creating a better understanding among the emergency planning and response community and by suggesting a series of adjustments that could reduce the vulnerability of water systems.

There are numerous research questions concerning technical aspects of water supply, water system susceptibility to disaster, and the nature of hazards. These questions concern such things as earthquake-resistant design of public utility systems and models to analyze system reliability. While important, these will be left to those groups traditionally concerned with technical questions, and we will focus instead on a limited set of research needs that should be of interest to FEMA in its responsibility for assessing the general state of preparedness and as a promoter of improved planning techniques. As an outcome of its emergency water program, the Corps of Engineers will probably identify many of the same needs. The following needs are therefore also offered for consideration of the Corps.

5.1 PROGRAM NEEDS

5.1.1 Supplemental Guidelines for Preparing Integrated Emergency Management Plans

All local jurisdictions receiving Emergency Management financial support from FEMA are required to complete and submit a set of forms developed for FEMA's integrated Emergency Management activities (FEMA, 1985a). The procedure for completing the forms has the local jurisdiction (1) list possible hazards, (2) catalog the resources available to respond to the anticipated hazards, and (3) develop a multi-year plan to acquire needed resources. There is no guidance as to how the planner is to determine preparedness resources or how to create a realistic development plan. Practical guidelines for determining the effectiveness of various adjustments for provisioning water in an emergency should be prepared to supplement the present guidelines. Techniques for analyzing cost, resource requirements, risk reduction, and barriers to implementation should be included, followed by techniques for choosing among the adjustments. Sources of data and techniques of data analysis would be useful additions. Suggestions on overcoming institutional barriers and "marketing" adjustments should also be incorporated.

5.1.2 Background on Water Systems for the Local Planner

The analysis suggested in 5.1.1 above will be accomplished by the technical staff of the water system. For the local emergency planners to solicit the support of the technical staff, to give them guidance in performing the task, and to integrate the emergency water plan into the greater community plan, they must have a basic understanding of water systems, the impact of disasters on these systems, and the disaster adjustments commonly used for utilities. A supplement to the integrated Emergency Management guidelines should be developed to help the local planner interact with utilities. The document should focus on disaster-related issues and should be free of technical jargon.

5.2 RESEARCH NEEDS

5.2.1 Vulnerability of Water Systems

We have shown that the chief concern relative to provisioning of water in emergencies is the ability of water systems to continue to function during the postdisaster period. This depends on the vulnerability of these systems, that is, their state of preparedness and their ability to respond appropriately. The actual vulnerability of this nation's water systems to emergencies is simply not known, this despite the fact that FEMA attempts to ascertain the preparedness of various systems to respond to emergencies through its integrated Emergency Management activities (FEMA, 1985a and 1985b). The difficulty with the FEMA assessment is that emergency planners are asked only if utilities as a group (they are not distinquished one from another) have developed procedures for emergency operations. No evaluation of vulnerability is required. This probably reflects the recognition that individual emergency planners are not qualified to perform such evaluations.

Open questions that research could help resolve include: Are water systems becoming more vulnerable over time? What types of systems are most vulnerable? What are the major factors contributing to vulnerability? What practical adjustments can be instituted for each major factor contributing to vulnerability?

Questions concerning the impact of nuclear attack on the provisioning of water are particularly troublesome. For example, what are reasonable strategies for providing safe water to displaced populations during the recovery period after a nuclear attack in light of the possibility for long-term outages of ultilities? Also, it is probably time to challenge a long-standing assumption of the civil defense literature that people will provide themselves with adequate water to last through the shelter period. As demonstrated in the discussion of nuclear attack vulnerability, any strategies adopted should be based on more realistic assumptions about response capabilities and im-

pacts than those used in past assessments. In particular, assumptions about targeting strategies, possible effects of EMP, and worker behavior should be reexamined. As a consensus on the threat of Nuclear Winter develops, it should be included in these studies.

An assessment of the vulnerability of the 273 largest water systems would be a worthwhile research undertaking because of the large number of people they serve. This would, however, ignore the important role that small systems are likely to play. They are the least prepared and most vulnerable. Furthermore, they would carry a disportionate burden in the recovery of the fragmented and decentralized economy left by a nuclear attack. The number of small and medium systems, nearly 60,000, makes a statistical sample of their preparedness prohibitively expensive. An assessment of their vulnerability would have to be based on a carefully selected sample, expert opinion, and a review of available literature.

5.2.2 Improvements in the Design and Acceptance of Preparedness Adjustments

We have described a number of adjustments that would act to decrease the vulnerability of water systems. Yet, these adjustments have only been partially adopted, raising the possibility of unacceptable levels of vulnerability. Most discussions of emergency water adjustments are limited to economic and engineering considerations. However, institutional and behavorial-based adjustments are probably equally important and need more research. Examples of questions such research might explore include (1) Why are adjustments not adopted? (2) What incentives would be needed to encourage adoption of adjustments? (3) What practical programs can various levels of government develop to promote adoption? (4) How can regional cooperation among utliites be promoted? (5) How would industry or the public accept the water priorities and allocations to be developed by the Corps of Engineers? (6) How can fear or concern for family by water works employees be mitigated during an emergency to increase their productivity and effectiveness? and (7) since communication between waterworks staff and disaster management officals, city and State officals, and the press has been a problem in past emergencies, how can communication be improved?

Social science techniques, including the analysis of individual and institutional behavior, techniques for motivating appropriate behavior, policy analysis, or analysis of relief equity and effectiveness, should be employed in any research focusing on the design and acceptance of adjustments.

5.2.3 The Impacts of Nuclear Attack on Water Systems

Many unanswered questions remain concerning the impact of nuclear attack on water systems. Useful research can be done on any of the following:

1. the effect of EMP on utilities,

2. possible temperature and drought impacts of Nuclear Winter on utilities,

3. the significance of the almost total dependence on electrical utilities by water systems - a national assessment,

4. the feasibility of stockpiling potable water and waste water treatment chemicals,

5. the difficulty in cleaning water supplies after attack and a plan for accomplishing the cleanup,

6. the effect on water supplies by spills of toxic substances, and

7. expedient means of obtaining potable water in the post-shelter period before water systems are restored.

6. A RECOMMENDATION FOR INTERAGENCY COOPERATION

In 1983, the U.S. Corps of Engineers (USACE) assumed the lead agency responsibility related to water preparedness functions assigned under Part 7 and related parts of Executive Order 11490. Since 1983, the USACE has actively developed an ambitious emergency water planning program to address the full spectrum of emergencies. The scope of the program and projected funding levels suggest that the provisioning of water may at last be getting the attention it deserves from the Federal government.

The USACE instructions for developing the Emergency Water Program (EWP) list the following deliverable products and services for major program activities:

1. Operational Readiness

   Emergency water hazard analysis
   EWP coordination/communication network
   Interim response capability
   Federal Regional Center plans

2. Research and Development

   Prototype studies of two cities
   Department of Defense emergency water needs
   Industry emergency water needs
   Water conservation planning concepts
   Water claimancy concept study

3. Assistance to State and Local Governments

   Information exchange seminars

4. Federal Agency Support Activities

   Regional coordinating groups

Of special note is the strong emphasis on research and, in particular, on two prototype studies in which the USACE will support the development of emergency water plans for two cities. These efforts will be carefully monitored and the experience extrapolated to other cities in the form of guidelines for emergency planning. Another activity of interest to FEMA is the claimancy concept research which will result in guidelines governing priorities and allocations of water and water support resources. As the final arbitrator in claimancy conflicts, FEMA must understand the basis for decisions in the water area.

It is apparent that many of the activities and interests of the USACE coincide with those of FEMA. To avoid duplication and perhaps conflicting inputs to local planners, the guidance supplied by the two agencies must be consistent and well coordi-

nated. To ensure this, we recommend that any research done by FEMA in the provisioning of water be in support of and part of the Emergency Water Program through interagency agreement. In this way, FEMA can give the USACE the benefit of its experience in local area disaster planning while promoting its interest in integrated emergency management. It would allow FEMA to contribute to emergency water research in a meaningful way with a minimum investment.

We suggest that the topics listed in Sect. 5.2 be the starting point for negotiations on a cooperative effort. For example, FEMA may choose to support the social science aspects of the USACE research activites since this area is often slighted in water research. The form of the support should fit programmatic needs of both organizations and available resources. The form could range from the temporary assignment of FEMA or contractor staff to USACE to straight funding support. Whatever form is selected, the advantages to both agencies and to the disaster community at large are sufficient to justify cooperative research.

REFERENCES

Ayre, Robert S. 1975. Earthquake and Tsunami Hazards in the United States: A Research Assessment, NSF-RA-E-75-005, The Institute of Behavorial Science, The University of Colorado.

Barnes, P. R. 1984. "Electromagnetic Pulse (EMP) and its Implications for Electric and Electronic Systems," presented at The Citadel, April 18, 1984, Charleston, S.C.

Baxter, S. S. 1976. The Trenton Story, J. AWWA, December 1976. 631-634.

Clark, Champ 1982. Flood, Planet Earth Series, Time-Life Books, Alexandria, Virginia.

Cochrane, Harold C. 1975. Natural Hazards and their Distributive Effects, NSF-RA-E-75-003, Institute of Behavioral Science, University of Colorado.

Defense Civil Preparedness Agency 1979. Emergency Sewage Procedures During Crisis Relocation, RS 2-8-30, Department of Defense.

Defense Civil Preparedness Agency 1977. Reception and Care Planning Guidance for Host Communities, CPG-2-8-14, Department of Defense.

Emergency Water Administration 1981. Water Emergency Plan, U.S. Department of the Interior.

Federal Emergency Management Agency 1985a. Hazard Identification, Capability Assessment, and Multi-Year Development Plan, Overview, CPG 1-34, Washington, D. C.

Federal Emergency Management Agency 1985b. Hazard Identification, Capability Assessment, and Multi-Year Development Plan for Local Governments, CPG 1-35, Washington, D. C.

Goodrich, David W., et al. 1967. Vulnerability of the Water and Drainage Systems in San Jose, Stanford Research Institute.

Haaland, Carsten M., C. V. Chester, and E. P. Wigner, Survival of the Relocated Population of the U. S. after a Nuclear Attack, ORNL-5041, Oak Ridge National Laboratory.

Hooker, Donald 1980. An Overview of the Metropolitan Washington Area Water Supply Emergency Agreement, Paper presented at the AWAA Meeting, Chesapeake Section, in Ocean City, Maryland, September 4, 1980

Jensen, C. F. 1967. Shelter Water Supply Study: Cost Implications of Emergency Sources, Stanford Research Institute.

Lindorff, D.E., and Keros, C. 1977. Groundwater Contamination: Problems and Remedial Actions, Environmental Geology Notes, Illinois State Geological Survey.

Katz, A. M. 1982. Life After Nucalear War, Ballinger Publishing Co., Cambridge, Mass.

Nevin, Robert L. 1969. Vulnerability of the Albuquerque Water Supply System, Stanford Research Institute.

Nevin, Robert L. 1970. Vulnerability of the Detroit Water Supply System, Stanford Research Institute.

New England River Basins Commission 1980. Before the Well Runs Dry: Literature Survey and Analysis of Water Conservation, RALI Program, U.S. Department of the Interior, Washington, D.C.

Office of Civil Defense 1964, 1966. A Prototype Manual on Civil Defense Aspects of Waterworks Operations, Phase I and II, Department of Defense.

Office of Civil Defense 1966. Basic Course in Emergency Mass Feeding, Handbook H-15, Department of Defense, Washington, D.C.

Office of Civil Defense 1965. Reducing the Vulnerability of Water Supply Systems, Professional Guide Series, PC-80-24, Department of Defense, Washington, D. C.

Overman, Michael 1969. Water, Solutions to a Problem of Supply and Demand, Doubleday & Company Inc., Garden City, N. Y.

Pavia, R.A. and Thomas, C. 1977. "The Winter of 1976-1977 in Chicago, Ill.," J. Amer. Water Works Assoc., 623-628.

Public Health Service 1966. Civil Defense Aspects of Municipal Water Systems, U.S. Department of Health, Education, and Welfare, Washington, D. C.

Schinzinger, Roland, and Fagin, H. 1979. Emergencies in Water Delivery, California Water Resources Center, University of California.

The Oregonian 1985. "Water Bills in Millions Faces City," Vol. 135 No. 44, 396, Portland, Oregon, May 22, 1985.

Turco, R.P., et al. 1983. "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," Vol. 222, No. 4630, Science, December 1983.

USGS 1984. National Water Summary 1983 - Hydrologic Events and Issues, Water-Supply Paper 2250, U. S. Geologicay Survey.

Utah Office of Emergency Services 1976. Natural Disaster Hazard Analysis, State of Utah, Salt Lake City, Utah.

Viessman, Warren and Hammer, Mark J. 1985. Water Supply and Pollution Control, Harper & Row, Publishers, New York.

Warrick, Richard A., et al. 1975. ,Drought Hazard in the United States: A Research Assessment, NSF-RA-E-75-004, The Institute of Behavioral Science, The University of Colorado, Denver, Colorado.

Water Resources Council 1978. The Second National Water Assessment, Washington, D.C.

White, Gilbert F. and Haas, J. Eugene 1975. Assessment of Research on Natural Hazards, MIT Press, Cambridge, Mass.

Wisconsin Division of Emergency Government 1981. Hazard Analysis for the State of Wisconsin, Wisconsin Department of Administration, Madison, Wisc.

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